REPORT DOCUMENTATION P[age]

AFRL-SR-BL-TR-98-

0279

[Approved] [OMB No.] 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
AUGUST 1997

3. REPORT TYPE AND DATES COVERED
Final Technical Report 11/15/93 05/14/97

4. TITLE AND SUBTITLE
Remote Sensing of Inner Heliospheric Plasmas

5. FUNDING NUMBERS
2311/AS
F49620-94-1-0070

6. AUTHOR(S)
Bernard V. Jackson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Regents of the University of California
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0934

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dr. Henry Radoski
AFOSR/ NM
Building 410
Bolling AFB DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19980331 061

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release;
distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Solar disturbances produce major effects on the corona, the solar wind, the interplanetary medium, and the Earth along with its magnetosphere. New techniques have been developed under this grant for studying plasma disturbances in the inner heliosphere by remotely sensing them. These techniques have used data from the HELIOS spacecraft zodiacal light photometers, *in situ* data and a variety of other spacecraft and ground-based instruments. The zodiacal-light photometers on board the two HELIOS spacecraft (data coverage from 1974 to 1986) provided the first reliable information about the heliospheric masses and shapes of propagating disturbances. The investigations into the physics of the disturbances sensed by these techniques, and the ability to forecast them, have been underway during the contract. The data analyses have used YOHKOH spacecraft observations, Sacramento Peak Observatory and Mauna Loa (Mark III) coronagraph data to map solar surface features. In addition, interplanetary scintillation (IPS) data from the Cambridge, England, Nagoya, Japan, and Ooty, India radio telescopes plus ULYSSES and IMP *in situ* data have been used to determine present-day conditions in the solar wind.

14. SUBJECT TERMS
Helios photometer data, in situ data

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

The Physics of Remotely-Sensed Heliospheric Plasmas

I. Introduction

The outermost parts of the solar atmosphere - the corona and solar wind - experience dramatic perturbations related to flares and mass-ejection transients. These disturbances extend to the Earth's magnetosphere and to Earth itself. In the past, observations of the origins of these disturbances in the lower corona have been restricted to coronal emission-line observations and the meter-wave radio band, but since the 1970's we have seen the addition of powerful new observing tools for observation: sensitive coronagraphs, both in space and at terrestrial observatories; X-ray imaging telescopes; low-frequency radio telescopes; space-borne kilometric wave radio receivers; and interplanetary scintillation data.

The primary object of earlier research has been to understand the physics and spatial extents of heliospheric structures such as coronal mass ejections and streamers. In comparison with spacecraft *in situ* and ground-based data, this leads to a better determination of the total mass and energy of these structures. In addition, we have addressed the question of how easy these features are to observe and how we can forecast their effects at Earth. This study has resulted primarily from analyzing the data from the zodiacal light photometers on board the HELIOS spacecraft.

We describe our recent results on HELIOS photometer observations of mass ejections, corotating density enhancements and other heliospheric features partially supported by a previous AF grant titled 'Remote Sensing of Inner Heliospheric Plasmas' in Section II of this report. The new research section (Section III) emphasizes the studies we have begun under the current contract 'The Physics of Remotely-Sensed Heliospheric Plasmas' and concludes with a list of papers and as well as a list of the personnel that have been supported by this contract. Conclusions are presented in Section IV.

II. Scientific Background and Recent Results

In the lower corona the major ejections observed in Hα are termed "eruptive prominences," and are typically associated with a particular kind of flare characterized by two expanding bright ribbons in the chromosphere and a growing system of coronal loops rooted in these ribbons (e.g., Švestka, 1986). The X-ray loops appear to move gradually upward in a steady sequence of diminishing temperature and velocity, and their emission decays with time scales of hours (e.g., Švestka, 1981). These long-duration X-ray events (Kahler, 1977; Sheeley *et al.*, 1983) are known to have a strong association with the ejection of mass into the corona (the coronal transient), the acceleration of interplanetary protons (Kahler *et al.*, 1978), and meter-wave radio phenomena (Webb and Kundu, 1978).

Recent solar X-ray imaging observations (including those from the Japanese YOHKOH spacecraft) have added new data for the phenomenological picture of the origins of coronal mass ejections. Using X-ray imaging and coronagraph data, Harrison *et al.* (1985) argue that rising X-ray arches are involved in the initiation of coronal mass ejections, and in

some instances flares (when they occur) are secondary activity at the feet of the arches. We now have evidence that these long-enduring coronal structures may also trap extremely hot thermal sources (e.g., Tsuneta *et al.*, 1984). Cliver *et al.* (1986) argue that such extended hard X-ray bursts are evidence of the acceleration of non-thermal particles in the post-flare loops following mass ejections. X-ray imaging data also revealed large, long-enduring X-ray arches associated with metric radio continua following flares on 21-22 May 1980 (Švestka *et al.*, 1982a), several times on 6 and 7 November 1980 (Švestka *et al.*, 1982b; Švestka, 1984; Farnik *et al.*, 1986) and on 20-22 January 1985 (Hick *et al.*, 1987). These arches coexist with the loop systems, but extend to higher altitudes, survive longer, and coincide in space and time with coronal metric radio phenomena such as type I (short, segmented in time and frequency) and type IV (broad-band continuous) radio emission. Extended bursts of non-thermal hard X-ray emission (Frost and Dennis, 1971; Hudson, 1978) provide another sign that major energy release and particle acceleration may take place in the corona high above, and for long periods after, the disturbance at the solar surface.

In association with filament eruptions or large solar flares, the Sun emits clouds of ionized gas and entrained magnetic fields (the "coronal mass ejection") and hydrodynamic disturbances (the "shock wave") responsible for some of the magnetic-storm sudden commencements at the Earth. Coronal mass ejections (CMEs) are the most dramatic disturbances of the heliospheric mass distribution and the ones first detected in the HELIOS photometer data (Richter *et al.*, 1982). The quantitative study of mass ejections essentially began with the Skylab coronagraph (e.g., Rust and Hildner *et al.*, 1980), and has been greatly enhanced by the advent of new coronal instruments. There are data available from the P78-1 and SMM spacecraft, and from mountaintop observatories such as Sacramento Peak and Mauna Loa. In addition, ground-based radio observations provide information on interplanetary scintillations, which are especially useful at high ecliptic latitudes and large solar elongations.

As shown by Webb *et al.* (1980), the ejected coronal mass at the time of a solar flare may be more important energetically than its chromospheric manifestations. Thus it is imperative to study the masses and 3-dimensional structures of the mass ejections in order to understand the flare process. This provides an additional incentive for the study of mass ejection phenomena, over and above our interest in the physical mechanisms involved in the acceleration of mass and particles associated with the mass motions themselves. The observations from the HELIOS spacecraft photometers (Leinert *et al.*, 1981) provide a link between coronal observations and those obtained *in situ* near Earth. Prior to these observations, the most frequently used way to remotely sense information about the interplanetary medium was by radio data.

II.A. The HELIOS Photometer Data

The HELIOS spacecraft, the first being launched into heliocentric orbit in 1974, contained sensitive zodiacal-light photometers (Leinert *et al.*, 1981). Each of the two HELIOS spacecraft contained three photometers for the study of the zodiacal-light distribution. These photometers, at 16°, 31°, and 90° ecliptic latitude, swept the celestial sphere to obtain data fixed with respect to the solar direction with a sample interval of about five hours. The spacecraft were placed in solar orbits that approached to within 0.3 AU of the

Sun. The photometers of HELIOS 1 viewed to the south of the ecliptic plane; HELIOS 2 to the north. These photometers were first shown to be sufficiently sensitive to be able to detect variations in brightness from coronal mass ejections by Richter *et al.* (1982).

An evaluation of these photometer brightness variations provides us with an opportunity to extend the coverage of transient phenomena produced by the Sun in the corona and to reduce some of the ambiguities in the coronal data obtained from the Earth's direction. This stereoscopic capability has been a major objective of many proposed deep-space probes, but some of the desired capability exists in these serendipitous HELIOS data. In many mass-ejection events, the mass can be followed right past the HELIOS zenith direction and into the antisolar hemisphere. In the HELIOS data, the contributions of background starlight and zodiacal dust have been calculated and removed from each photometer sector by Leinert and his colleagues, and the complete data set was made available to the National Space Science Data Center (NSSDC). Optical disks containing this data set is now available at UCSD and on request from NSSDC.

The image processing system we have developed has been demonstrated by construction of images of the interplanetary medium in video form for specific mass ejection sequences of the data; these data and additional images of specific events have been used to trace the time history of a variety of density enhancements. At UCSD we have used groups of students to analyze and present these data for use by others. These data are of interest to the Air Force for several reasons: 1) The understanding of the processes in the heliosphere and its plasma environment are of great importance to the Air Force that operates spacecraft systems and at times maintains a manned presence in space. 2) The ability to observe the outward propagation of structures from the Sun allows researchers to forecast their arrival at Earth. This in turn leads to both a better understanding of how these features interact with the Earth environment and how to determine a more accurate prediction of their effects on Air Force space and communication systems. 3) In recent years the Air Force has proposed placing an orbiting Solar Mass Ejection Imager (SMEI) (Jackson *et al.*, 1995; Keil *et al.*, 1996) in space to forecast the arrival at Earth of solar mass ejections, heliospheric shocks, and corotating dense regions. By studying the data from the HELIOS spacecraft photometers it is possible to assess the usefulness of the data which an Earth-based imager such as SMEI would provide.

II.B. HELIOS Photometer Events Data Set

A major achievement of past research at UCSD has been the measurement of interplanetary masses and speeds of CMEs observed by coronagraphs, interplanetary scintillation measurements, and from *in situ* spacecraft measurements. A 2-D imaging technique which displays HELIOS photometer data has been developed here. The combination of these images with data from the perspective of Earth has been used to provide stereoscopic views of CMEs for many of the events studied. With HELIOS photometer data it is possible to sample the brightness of any given ejection over a far greater range of heights at one instant than with coronagraph instrumentation. Also, by measurement of the outward motion of an ejection determined from the photometers, the total extent of mass flow past a given latitudinal set of photometer sectors can be found and then checked by the second set of photometer sectors (*e.g.*, see Jackson, 1985). The HELIOS data show that not only do CMEs supply significant mass to the interplanetary medium, but also

that the mass flow from the Sun extends over times that can be greater than one day and in amounts somewhat greater than measured by coronagraphs. Webb and Jackson (1988) were able to determine the occurrence rate of plasma events from solar minimum to near maximum from the HELIOS 2 90° photometer and showed that the rate increased significantly over that period.

We followed the mass ejection of 7 May 1979 from near the solar surface to the furthest extent that can be observed by HELIOS (Jackson *et al.*, 1988). Near-surface observations of this mass ejection from the Wroclaw observatory show the Hα manifestations and position of the associated loop-like eruptive limb prominence near the solar surface. This ejection accelerated between the SOLWIND field of view, and when observed later by HELIOS eventually reached a speed of about 500 km s^{-1}. The analysis also includes UCSD IPS measurements which show an enhancement of the scintillation level and speed during passage of the excess mass of small-scale turbulence which compares favorably with the 500 km s^{-1} speed of bulk motion obtained from HELIOS data. A three-dimensional reconstruction technique developed at UCSD is introduced in the same paper (Jackson *et al.*, 1988).

When the entire HELIOS photometer data set was available on optical disk, we began filling in data for the heliospheric southern hemisphere using observations from HELIOS 1. This is particularly important because the time interval through which HELIOS 1 operated spanned eleven years (one complete solar cycle) from 1974 through 1985. The HELIOS 2 90° photometer was normally not available for this analysis on the zodiacal light data tapes because of a questioned absolute calibration due to the presence of the Large Magellanic Cloud and an uncalibrated wobble of the HELIOS 1 spacecraft over its 6-month orbital period. However, we are interested primarily in the short-term variations in the data temporal sequence. Using data from the optical disk at UCSD and a data set normally not used but available on the optical disk, we displayed the HELIOS data for all orbits of the HELIOS 1 spacecraft and selected all of the significant events observed in the data (~300) for further study.

Using this extensive list we published a preliminary study of the solar cycle variation of these data (Webb and Jackson, 1992; 1993) showing that the events are far more numerous during solar maximum when more sunspots are present. Over 160 CMEs have now been observed and catalogued in the HELIOS 1 and 2 photometer data. Since the HELIOS photometer data are well calibrated in intensity, and very consistent in spatial and temporal characteristics, it has been possible to determine not only the solar cycle occurrence rate of mass ejections, but also their mass flux, size and temporal distribution. These results have been presented and published in many papers (Webb and Jackson, 1990; 1992; 1993, Webb *et al.*, 1993a; 1993b and Jackson *et al.*, 1993). The analyses have also lead to a preliminary paper by Webb and Crooker (1991) that shows the heliospheric current sheet is dynamic, and that CMEs are often involved with these current sheet dynamics. Both *in situ* and HELIOS photometer data are used to sort out the different structures in these complex regions of space (Crooker *et al.*, 1993; Shodhan-Shah *et al.*, 1993).

The Jackson (1991b) presentation at the Solar Wind 7 conference in September in Goslar, Germany was a video of mass ejections observed by the HELIOS photometers. These videos show a sequence of images of five mass ejections as they move outward from the Sun to the farthest distances observed by HELIOS. The Jackson (1991c) review

paper presented at the first SOLTIP conference in September in Liblice, Czechoslovakia compares the HELIOS photometer data with IPS data for specific time intervals. In this paper we compared several mass ejections observed by HELIOS with available data from IPS velocity measurements from UCSD (Coles and Kaufman, 1978) and additional data from IPS using the Cambridge, England array (Hewish and Bravo, 1986). The SOLTIP analyses in some instances have been published previously (*i.e.*, Jackson *et al.*, 1988), but here the information is gathered together. In the final portion of the review, there is an attempt for the first time to reconcile the differences between the Cambridge IPS and the HELIOS masses for a mass ejection observed leaving the Sun on 27 April 1979.

In order to understand the extent and significance of CME events in the HELIOS data, it has also been necessary to define the normal or quiet solar wind conditions in the observations. The automatic HELIOS analysis techniques we developed have allowed the display of photometer data into month-long data sequences in the form of synoptic maps (as in Hick *et al.*, 1990). In the preliminary report (Hick *et al.*, 1992) we were able to compare these maps with IPS velocity maps (Rickett and Coles, 1991), K-coronameter maps (Fisher and Sime, 1984) and magnetic field maps (Hoeksema *et al.*, 1983). The HELIOS observations clearly show the organized heliographic equator enhancement of density at solar minimum and a depletion of the density over the solar poles. As solar maximum approaches, the enhanced density increases in latitude until at the time of maximum the whole of the Sun is surrounded by dense solar wind. This effect has been concluded from circumstantial evidence nearer the solar surface by others, but has never before been as directly observed above the primary region of solar wind acceleration (where the HELIOS photometers were sensitive).

II.C. Three-Dimensional Reconstruction Technique

The true three-dimensional geometry of mass ejections has long been a question for researchers. Much of the information of recent years suggests that a CME fills a large three-dimensional volume, but that CMEs may not be configured like either a simple arch or a bubble as once thought. While some of these results have come from the HELIOS analysis and from coronagraph (*e.g.*, MacQueen, 1993) observations, a larger amount of evidence about their large extents is inferred from the positions of CMEs observed *in situ* and the spatial locations of them near the Sun (*e.g.*, Sheeley *et al.*, 1985) sensed either by coronagraphs or other techniques. The importance of the CME shape goes beyond a simple accounting of its structure and its cross section movement through the heliosphere. The measurements of magnetic field *in situ* for CMEs imply that portions of them contain highly organized current systems which may extend back to the solar surface. The CME shape is derived from the processes (as yet poorly known) which drive the CME outward from the Sun. Modelers need to know the organization of the mass within the ejection to determine how the energy needed to eject the material was distributed.

The unique stereoscopic aspect of the HELIOS data can be fully utilized if three-dimensional models of the CMEs can be produced for specific events. The 7 May 1979 and 24 May 1979 events were ideal in this respect because they were well-observed by both SOLWIND and HELIOS 2 when the spacecraft were widely separated from one another in solar longitude. We have developed a computer program which constructs excess interplanetary and coronal densities in three dimensions, projects the brightness of this material to the SOLWIND or HELIOS views, and then iterates to find the best

density fitting the observed brightnesses from both instruments. Two different versions of this type of computer assisted tomography or CAT-scan analysis have been developed at UCSD: an algebraic reconstruction technique (ART) and an iterative least squares technique (ILST). In the HELIOS view both brightness and polarization brightness are matched by the constructed density distribution.

III. Research Completed Under This Contract

During this contract we completed five research articles begun under the previous contract 'Remote Sensing of Inner Heliospheric Plasmas' and have written or helped write 30 additional articles on several aspects of the solar-terrestrial connection. Heliospheric photometer analysis studies continued for both the data set as a whole and for single CMEs as in the case of the density structure CAT analysis for the 24 May 1979 CME. We have also made available the extensive *in situ* data set from the HELIOS spacecraft to be used by others in comparative studies with the photometer data. We have studied various aspects of the quiet solar wind using a variety of techniques also used to present HELIOS photometer data, and we discovered in comparison with near-Sun coronal data that solar active regions form a significant component of the solar wind. We also discovered from Sacramento Peak coronagraph data that high coronal temperatures appear to follow the heliospheric current sheet as defined by magnetic field data. This implies an organized, systematic heating of the corona near the current sheet. Finally, in late 1995 we began a far more comprehensive program to determine three-dimensional solar wind structure by using the perspective views of it provided by both solar rotation and outward solar wind motion.

III.A. Coronal Mass Ejection (CME) Mass in the Solar Wind

We published the table of the ~300 HELIOS 1 and 2 events at the beginning of 1994 (Jackson *et al.* 1994). This event catalog contains a distillation of the analyses performed to date on the events discovered in the HELIOS photometers. The events in the catalog were obtained using criteria which help assure a uniformity in data gathering over the 11-year span of HELIOS spacecraft operation. Studies from this data set form the basis for different analyses (and many papers) presented by our group and others. About 160 of the events in the list are definite CMEs. Another 56 of the events are definite corotating structures (CRSs).

All 160 certain CMEs have had speeds determined for them and a quality of this measurement is given for each. We have written a journal article and submitted the results of these speed observations (Jackson and Webb, 1997). Significant in this study is the observation that the speeds of CMEs measured by the HELIOS photometers are significantly greater than the speeds of the same CMEs measured *in situ* in the ecliptic. We expect that this is due both to the higher average speed of the solar wind out of the ecliptic and that CMEs are generally not directed toward the solar equator, but centered at solar latitudes of approximately 25°. In preliminary analyses we have determined the solar surface origins and masses of mass ejections by imaging individual events and comparing those from 1979 to 1985 with coronal mass ejections observed by SOLWIND and the SMM coronagraphs. These observations form the basis of a paper presented at the Solar Wind 8 conference in Dana Point California (Webb *et al.*, 1995).

We have determined heliospheric masses for nearly all of the CMEs in the list of 160 events. We describe the results of this analysis in a preliminary paper (Jackson and Webb, 1994). Following a study of Solwind coronagraph CME masses (Jackson and Howard, 1993), there are enough events present in the HELIOS CME sample to determine that the number of events versus mass approximately follows an exponential curve. The HELIOS masses, consistent within the two techniques used to derive them, do not agree well with the values measured from coronagraph observations. The most massive HELIOS events in general are approximately 3 times more massive than those derived by the Solwind coronagraph. The conclusion reached by Jackson and Webb (1994) about this discrepancy is that the small field of view available from coronagraphs limits the measurement of the complete mass of each CME.

The CME masses observed by HELIOS are a more direct measure of these masses present in the solar wind since the measurements are obtained beyond the region of primary solar wind (and CME) acceleration. The Jackson and Howard (1993) coronagraph CME mass determination shows that perhaps as much as 16% of the solar wind mass at solar maximum is comprised of CME mass. The Jackson and Webb (1994) preliminary analysis using 100 HELIOS-derived CMEs masses indicates that the mass associated with heliospheric CMEs confirms a value of at least 16% at solar maximum. This value is found with fewer assumptions about the unseen-by-the-coronagraph portion of CME mass in the HELIOS data.

An alternate technique was used to determine this solar wind CME mass by Leinert and Jackson (1997) while B. Jackson was a visiting research scholar at the Max Planck Institute for Astrophysics in Heidelberg October - December, 1996. The technique uses the HELIOS *in situ* and photometer data, IPS velocity and the assumption that solar wind densities and velocities combine so that solar wind momentum flux is constant. The solar cycle change in solar wind density indicates that approximately 15 - 20% more mass is present in the solar wind at solar maximum. This is presumably CME mass which is known to have a solar cycle variation of several orders of magnitude.

III.B. The Quiet Solar Wind

The HELIOS observations above the acceleration region of the solar wind allow a direct comparison of the solar wind density variations with solar wind speed from IPS velocity data. In particular Hick and Jackson (1994) in a preliminary analysis show that over different heliographic latitudes, momentum flux (mV^2) [and not mass flux (mV) or energy flux (mV^3)] is most likely conserved for different speed solar wind. The implications of this observation are far reaching, for it means that the total energy input by the Sun to the solar wind is constant over latitude and does not depend on the solar magnetic field near the solar surface.

Imbedded in this quiet solar wind are dense, slow solar wind regions which can be observed as corotating structures (CRSs) in the interplanetary medium. In our attempts to study these regions in the HELIOS data, we have expanded the study of the HELIOS photometer observations to solar surface and present-day measurements of these structures. During solar minimum conditions (as in 1994-96) these solar wind structures dominate and may be responsible for more solar-terrestrial interactive effects than CMEs.

To study the above data sets we have plotted each in a Carrington synoptic map

format similar to those presented in Figure 1. Data sets presented in this way (in terms of solar latitude and longitude) for one or a combination of solar rotations allow the ready comparison of stable solar features in two dimensions. This type of display enhances the ability to determine features associated with the Sun which corotate.

III.B.1. HELIOS-observed Corotating Structures (CRSs)

The CRSs observed by both HELIOS 1 and HELIOS 2 from the catalog of events (~56 total) show a general solar cycle variation that is similar in nature to the CME solar cycle variation - more are present at solar maximum. However, the variation with solar cycle of the CRSs number is by no means as pronounced as observed for the CMEs. As in the case of the CMEs, the CRSs are compared with the *in situ* manifestations of each event observed in the plasma and interplanetary magnetic field observed by the HELIOS spacecraft. The preliminary Jackson *et al.* (1993) study shows that 40% of these CRSs are associated with sector boundaries *in situ.* When projected back to the solar surface 40% of the CRSs also show a one-to-one association with the heliospheric neutral line determined by solar magnetic field data.

III.B.2. Heliospheric Densities

Near-Sun coronal brightness measurements to compare with the HELIOS observations have been available from coronagraphs at Sacramento Peak Observatory throughout the time interval of the HELIOS observations and up through the present (*Solar Geophysical Data, part I*, 1975-present). In order to map the HELIOS-observed CRSs with Sacramento Peak Fe XIV (green-line) data, we obtained these data digitally from R. Altrock at Sacramento Peak to compare statistically with the HELIOS data set. Comparison of the Sacramento Peak data with Wilcox Solar Observatory magnetic field data modeled to show the position of the heliospheric current sheet reveals a poor correspondence between the location of the current sheet and bright regions in Sac. Peak Fe XIV data, especially at solar maximum. A comparison of the Sac. Peak Fe XIV data on a rotation by rotation basis shows, however, a great similarity with interplanetary scintillation (IPS) enhancements (see section III.C.4.) observed from 0.5 to 1.0 AU even though this correspondence is not observed in the magnetic field data extrapolations (Hick *et al* 1995a). The comparison of Sacramento Peak data with similar data obtained from the Yohkoh spacecraft and with the IPS data show the same effect (Hick *et al.*, 1995b; Hick and Jackson, 1995).

The above indicates that solar active regions are major contributors of slow solar wind and that these regions add significant mass to the interplanetary medium. These regions (and not the heliospheric current sheet) dominate the IPS observations of the quiet solar wind at 1 AU. The regions of enhanced scintillation are generally regions of more dense solar wind (Hick *et al.*, 1995a; Jackson *et al.*, 1997b). This distinction would go unnoticed except that present-day understanding indicates that solar active regions are closed magnetic structures with solar wind flowing around them. Evidently, present-day understanding of these solar processes is not an accurate indication of what really happens to form the solar wind.

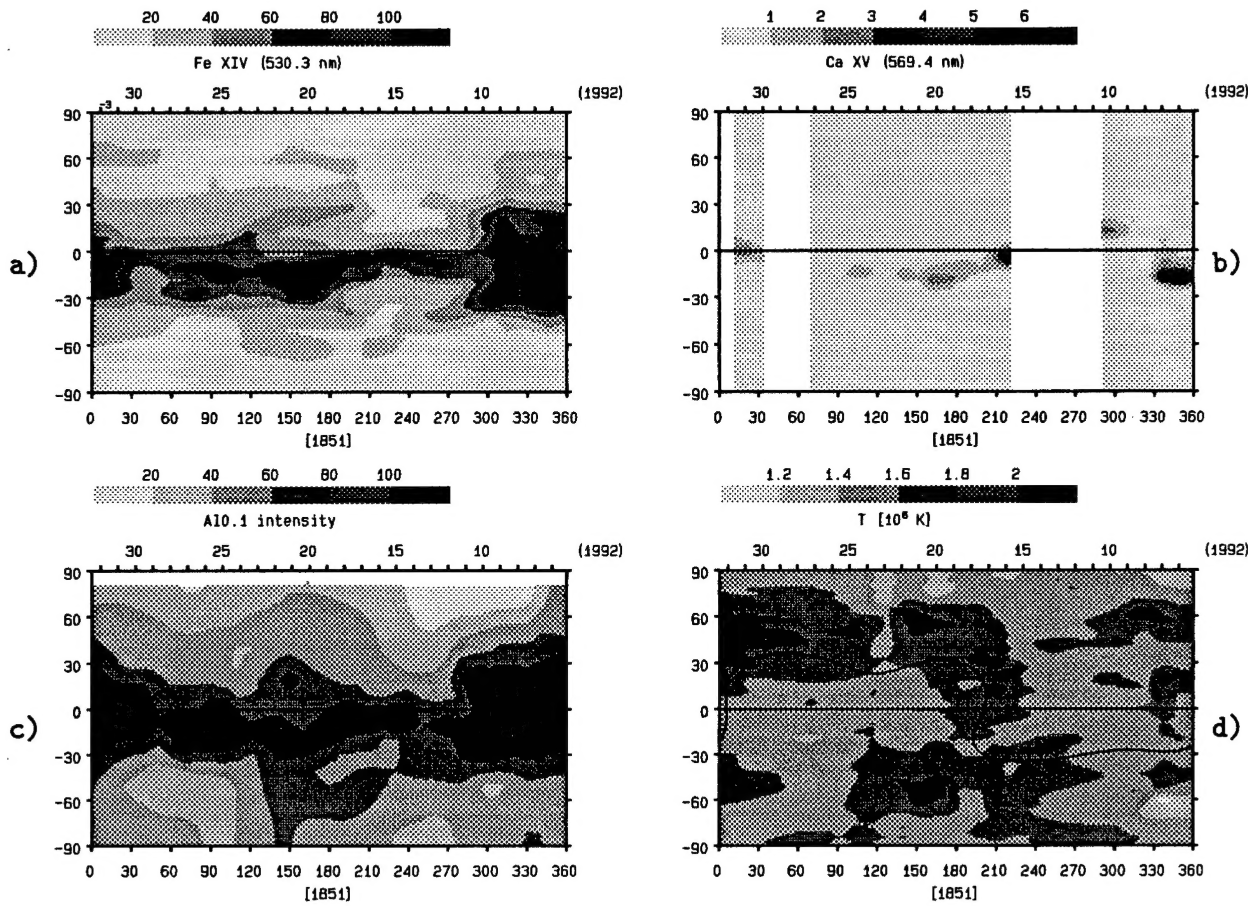

Fig. 1. Carrington synoptic map presentations of quiet sun structure for rotation 1851. (a) Sacramento Peak Observatory coronagraph data from Fe XIV limb scans at 1.15Rs. (b) Sacramento Peak Observatory coronagraph data from Ca XV limb scans at 1.15 Rs. (c) YOHKOH SXT central limb data (assumed at a height of 1.15 Rs degraded to a $10° \times 3°$ (Sac. Peak) resolution). (d) Coronal temperature data from Sacramento Peak Observatory coronagraph Fe X - Fe XIV line ratio data. Superimposed on this map is the heliospheric current sheet position as determined by the Wilcox Solar Observatory potential field model.

III.B.3. Heliospheric Temperatures

Since the mid-1980s, Sacramento Peak coronagraph data has been available from Fe X (red line) observations of the corona. The ratio of Fe XIV to Fe X brightnesses can be used to determine coronal temperatures (Guhathakurta, *et al.*, 1993). In our studies at UCSD, we produced the first Carrington synoptic maps of these temperature data and compared them with the Wilcox Solar Observatory magnetic field extrapolations of the heliospheric current sheet. One of us (Paul Hick) discovered that regions of high temperature (spotty at low coronal heights) have the uncanny habit of following the current sheet extrapolation. The current sheet extrapolation is accurate only above 2.5 Rs (solar radii) and the coronal temperature data were obtained at 1.15 Rs. Following this discovery, since February 1994 the Sacramento Peak Fe XIV and FeX observations have been made at solar heights up to 1.45 Rs. Analyses of these recent data at the highest solar heights show a simplification of the signal with height such that the region of high temperature forms a band centered on the heliospheric current sheet (Altrock *et al.*, 1994). These regions of high temperature in the Fe XIV/Fe X observations have little correspondence with the regions observed to be the brightest (but not ratioed as temperature) in the data.

If regions of high coronal temperature follow the current sheet, the simplest explanation of these high temperatures is that the currents associated with them heat the corona at that location. Present studies of this are aimed at certifying this relationship by other means such as extrapolations to measurements determined *in situ* by spacecraft and comparative associations with Yohkoh spacecraft SXT observations of the low corona. In addition, we attempt to compare the Sac. Peak temperature determinations with present models of coronal current strength at locations near 1.15 Rs.

III.B.4. Interplanetary Scintillation Observations

It has long been suggested that interplanetary scintillation (IPS) observations are the nearest to those from the HELIOS spacecraft and can be used similar to those from HELIOS to obtain information about the heliosphere. With very little effort, we have been able to modify our HELIOS photometer data display programs to produce interplanetary scintillation daily maps (images) of the sky around Earth much as was done at NOAA in their attempts to forecast the arrival of heliospheric disturbances at Earth. We obtained the IPS data daily by direct access from Cambridge, England, from the IPS array telescope there until radio interference beginning on September 10, 1994 made these data unusable. We clearly see heliospheric disturbances in these images that move rapidly outward from the Sun but note, as did the group at Cambridge and NOAA, that by the time most disturbances are well-observed, they have already reached the Earth. We have tried to improve the signal to noise present in the data by careful editing or displaying the data in the hope that they may become more useful as a disturbance forecast technique.

The Carrington synoptic presentation of data used to compare the HELIOS photometer data with other data sets has been modified to read daily IPS intensities and forecast the co-rotating or quiet solar wind component of the IPS level (Winfield *et al.*, 1993; Hick *et al.*, 1995a). These maps are made by ballistic trajectory projection of the measured values back to a single surface assuming these values are located at the point of closest approach of the line of sight to the Sun (The 'point-P' technique). As mentioned, these synoptic maps have been compared with other forms of solar surface and heliospheric *in*

situ data from Earth-orbiting IMP spacecraft. Each day we are able produce a forecast map for corotating IPS scintillation levels. From statistical comparison of the corotating component of the IPS intensity level shown in the map, we find a positive correlation between the forecast level of IPS intensity several days in the future and the proton density at Earth or the interplanetary magnetic field data when that day arrives. An even higher positive correlation to date has been found between the forecast IPS scintillation level and the Earth geomagnetic Ap index. We expect the co-rotating component of the solar wind to become more dominant as solar activity declines, and we expect our ability to forecast changes at Earth to increase with declining solar activity.

III.C. Three-Dimensional Reconstruction Technique - CMEs

The three-dimensional reconstructions of CMEs performed to date use two spacecraft observations of the CME material when the spacecraft are fortuitously situated so that they view CME material orthogonally. This analysis has advanced considerably following the use of display techniques available to us in IDL software at the beginning of this contract. These techniques have allowed the rapid display of three-dimensional structures. The reconstruction technique converges in an iterative fashion to a solution that shows the gross features of the excess ejected mass. This CAT-scan analysis is described in Jackson *et al.* (1988) and Jackson (1989), and forms the basis of paper on the subject of the 7 May 1979 CME by Jackson and Froehling (1995). A preliminary announcement of the results of the deconvolution of the 24 May 1979 CME which shows a "cap" of dense material (Jackson and Hick, 1994; Jackson, 1996). It is clearly apparent that data from the proposed Air Force Solar Mass Ejection Imager (SMEI) could not use a similar tomographic reconstruction technique to locate the three dimensional extent of CMEs and other heliospheric structures. No two-spacecraft views of CMEs are expected to exist when SMEI is present in Earth-orbit. Even so, three-dimensional structure for heliospheric disturbances have been mapped crudely by IPS observers by noting how the disturbance proceeds outward form the Sun with time (e.g., Behannon et al, 1991). When B. Jackson was a visiting guest scholar at the STELab, a branch of Nagoya University, Nagoya, Japan, from August - December, 1995, he began a project to formalize this idea using a least-squares tomographic reconstruction technique. Many of the analysis subroutines needed for this already existed to map the HELIOS photometer data into synoptic map format. Work on a similar project was already underway at the STELab to map global IPS velocity data of the quiet solar wind. So far, the technique, now in its beginning stage, has been used to successfully map structure in the quiet solar wind with unprecedented clarity.

III.D. Three-Dimensional Reconstruction Technique - Quiet Solar Wind

As the solar wind flows past an observer, the material in it changes its perspective relative to the observer simply by outward motion. To formalize the analyses of these global data sets one needs to keep track of the exact time each observation is made and in which direction. Combined with a three-dimensional model that depicts solar wind outward motion, it becomes possible to change the model to fit each observation since the line of sight response to the observed quantities is known or can be approximated. To assure that the reconstruction can proceed, enough perspective views need to be available

to reconstruct each solar wind structure accessed by the observations. The reconstruction proceeds in an iterative fashion with successive changes to the model required before the final fit is judged to be successful. In the analyses used to date we have used an least squares analysis to provide a criterion for goodness of fit of the model to observations. The decrease of the deviations of model from observations to a stable solution shows convergence to an answer. If different beginning approximations result in the same final result there is assurance that a single solution exists.

In the type of three-dimensional reconstructions performed so far we have assumed that the heliospheric structures mapped move outward without changing their location on the Sun. In other words, we have assumed that perspective views of them are the same over time or that the structures corotate. This is dictated generally by the number of data lines of sight which are currently too few to allow multiple perspective views of many different points as they pass the observer. Because of this we have limited measurements using this technique to reconstructions of quiet solar wind structures and to observations collapsed to a single synoptic map surface. The analyses performed to date have been described for IPS measurements by Jackson *et al.* (1997a; 1997b), Kojima *et al.* (1997a; 1997b) and Asai *et al.* (1997). By mapping the observations to many different heights, these corotating structures can be depicted in three-dimensions (Jackson *et al.* 1997b). An example of this presentation is shown in Figure 2. These depictions give an overview of heliospheric material around the and for instance, clearly show the solar wind Achimedian spiral structure formed by the outward-flowing dense material.

We have estimated line of sight responses for IPS velocity from the UCSD, Nagoya, Japan and Ooty, India, data sets and deconvolved them. We have also estimated line of sight responses of scintillation level from the Cambridge, England, Nagoya and Ooty IPS data sets and deconvolved them. In addition, we have used a similar technique to deconvolve the HELIOS photometer data set (Jackson and Hick, 1996; 1997). Each data set shows fairly similar results in general such as a longitudinal segmentation of structures which have low speed near the solar equator. However, with the exception of the HELIOS photometer and UCSD IPS velocity data set and the Cambridge IPS scintillation level observations and velocities from Nagoya, Japan, few data sets overlap.

We currently begin to relax the corotation assumption so that the reconstruction program will allow CMEs to be depicted. Although the amounts of data are insufficient from current data sets to allow much progress in this regard, we expect this to become far more important when SMEI begins to operate and provides up to 1000 times the quantity of data.

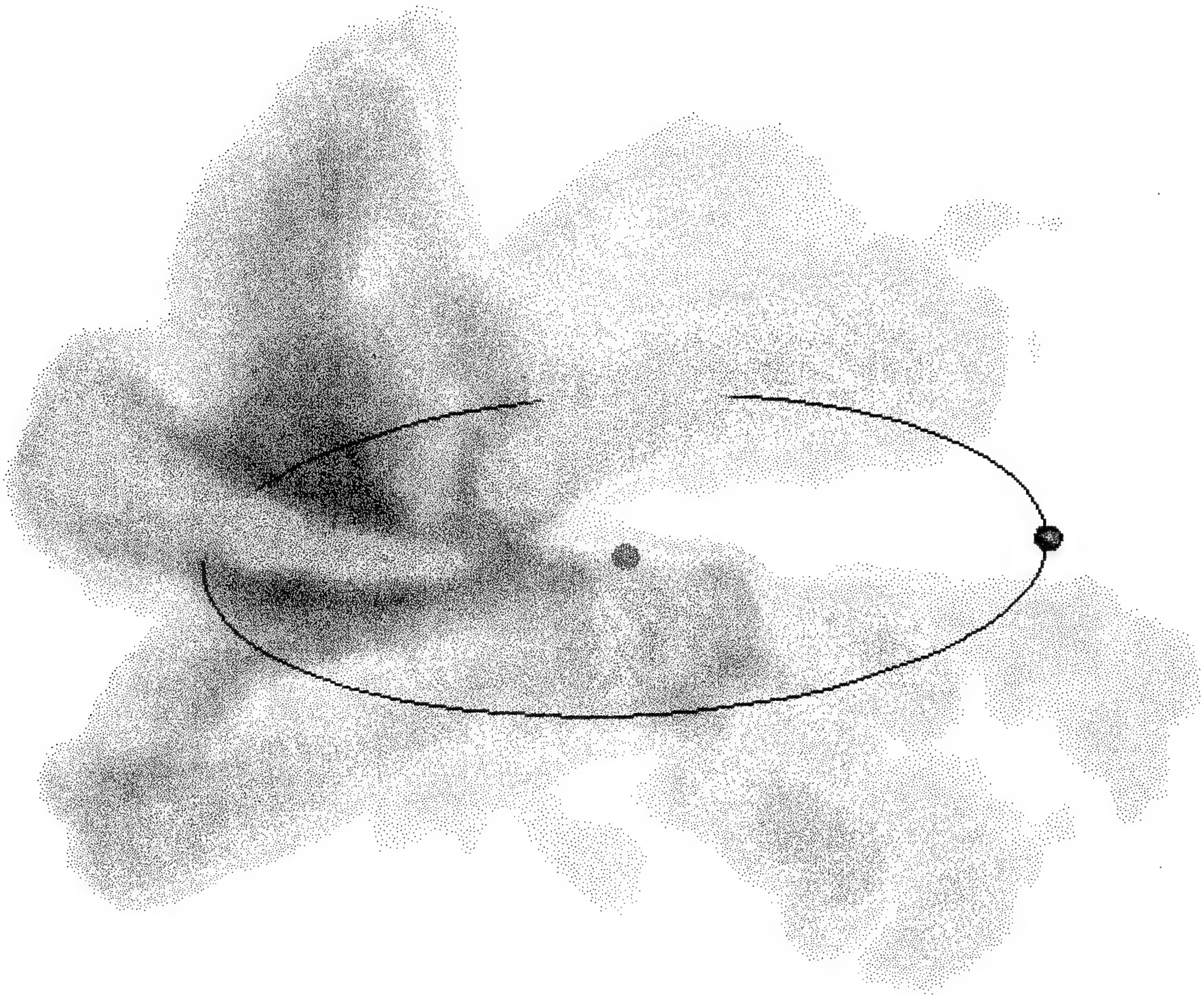

Fig. 5. The image is a view of inner heliospheric plasma density (to 1.5 times the distance of the Earth from the Sun) derived from a combination of interplanetary scintillation (IPS) Cambridge, England, intensity level and Nagoya, Japan, velocity data. The data were obtained from June 23, 1994 to July 20, 1994 (Carrington rotation 1884). The plasma density is normalized by the removal of a r^{-2} distance dependence. The Sun is depicted as a sphere in the center of the figure, and the Earth, a blue sphere on its orbit around the Sun. The view is from 30° above the plane of the solar equator. The image is obtained from a three-dimensional tomographic reconstruction of the plasma from perspective views of it available from outward motion of the plasma and solar rotation as explained by Jackson *et al.*, (1997b). The scintillation intensity level is calibrated in terms of density by comparison with IMP spacecraft densities at Earth. Observations are least-squares fit over the period of one solar rotation. Because of this limitation, only the corotating component of the heliospheric plasma density can be reconstructed from the data. Clearly seen is the three-dimensional Archimedean spiral structure of the dense heliospheric components of the solar wind during this solar minimum period. A video clip of the data from the above rotation can be accessed over the web at:

http://casswww.ucsd.edu/personal/bjackson/ipstomo.htm

III.E. Recent Publications

The publications which have benefitted from this grant or form the basis of research from it follow:

<u>Research Articles</u>

There have been 35 research articles and conference proceedings which acknowledge or have benefitted from the three-year AFOSR–94–0070 research contract. These articles are:

1. Webb, D.F., and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using Helios Photometer and In-situ Data", in the *Solar Terrestrial Predictions Workshop 4* in Ottawa, Canada 18 - 22 May, A. Huruska *et al.* (eds.), NOAA, Boulder (1993) (pg. 381-386). +

2. Hick, P. and B. Jackson, "Solar wind mass and momentum flux variations at 0.3 AU", *Adv. in Space Res.* **14** (1994) (pg. 135-138). +

3. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler and D.F. Webb, "A spaceborne near-Earth asteroid detection system", *Astronomy and Astrophys. Suppl. Ser.*, **108** (1994) (pg. 279-285). +

4. Jackson, B.V., D.F. Webb, P.L. Hick, J.L. Nelson, "Catalog of Helios 90° Photometer Events", *PL-TR-94-2040, Scientific Report No. 4*, Phillips Laboratory, Hanscom (1994) (51 pages). +

5. Jackson, B.V., "May 10, 1994 Annular Solar Eclipse Observations", *CalSpace News*, September (1994) (1 page).

6. Jackson, B.V. and D.F. Webb, "The Masses of CMEs Measured in the Inner Heliosphere", in the proceedings of the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, esa **SP-373** (1994) (pg. 233-238). +

7. Jackson, B.V. and P.L. Hick, "Three Dimensional Reconstruction of Coronal Mass Ejections", in the proceedings of the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, esa **SP-373** (1994) (pg. 199-202). +

8. Hick, P.L., B.V. Jackson, S. Rappoport, G. Woan, G. Slater, K. Strong and Y. Uchida, "Synoptic IPS and Yohkoh soft X-ray Observations", *Geophys. Res. Lett.*, **22** (1995) (pg. 643-646). +

9. Jackson, B.V. and H.R. Froehling, "Three-Dimensional Reconstruction of Coronal Mass Ejections", *Astron. Astrophys.*, **299** (1995) (pg. 885-892). +

10. Hick, P., B.V. Jackson, R.C. Altrock, G. Slater and T. Henry, "The Coronal Temperature Structure and the Current Sheet", in Solar Drivers of Interplanetary and Terrestrial Disturbances, Proceedings of 16th NSO/Sacramento Peak International Workshop, *ASP Conference Series*, **95**, K.S. Balasubramaniam, S.L. Keil and R.N. Smartt, eds. (1995) (pg. 358-365). +

11. Hick, P. and B.V. Jackson, "The Influence of Active Regions on IPS Measurements near 1 AU", in Solar Drivers of Interplanetary and Terrestrial Disturbances, Proceedings of 16th NSO/Sacramento Peak International Workshop, *ASP Conference Series*, **95**, K.S. Balasubramaniam, S.L. Keil and R.N. Smartt, eds. (1995) (pg. 470-471).

12. Keil, S.L, R.C. Altrock, S.W. Kahler, B.V. Jackson, A. Buffington, P. Hick, G. Simnett, C. Eyles, D.F. Webb, and P. Anderson, "The Solar Mass Ejection Imager (SMEI): Development and Use in Space Weather Forecasting", in Solar Drivers of Interplanetary and Terrestrial Disturbances, Proceedings of 16th NSO/Sacramento Peak International Workshop, *ASP Conference Series*, **95**, K.S. Balasubramaniam, S.L. Keil and R.N. Smartt, eds. (1995) (pg. 158-166).

13. Webb, D.F., B.V. Jackson and. P. Hick, "Geomagnetic Storms and Heliospheric CMEs as Viewed from HELIOS", in Solar Drivers of Interplanetary and Terrestrial Disturbances, Proceedings of 16th NSO/Sacramento Peak International Workshop, *ASP Conference Series*, **95**, K.S. Balasubramaniam, S.L. Keil and R.N. Smartt, eds. (1995) (pg. 167-170). +

14. Webb, D.F., R.A. Howard and B.V. Jackson, "Comparison of CME Masses and Kinetic Energies Near the Sun and in the Inner Heliosphere", in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury (1995) (pg. 540-543). +

15. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler, R.C. Altrock, R.E. Gold and D.F. Webb, "The Solar Mass Ejection Imager", in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury (1995) (pg. 536-539).

16. Hick, P. and B.V. Jackson, "Evidence of Active Region Imprints on the Solar Wind Structure", in *Solar Wind Eight*, D. Winterhalter, J.T. Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury (1995) (pg. 461-464). +

17. Hick, P., B.V. Jackson and R. Altrock, "Coronal Synoptic Temperature Maps Derived from the Fe XIV/Fe X Intensity Ratio", in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury (1995) (pg. 169-172). +

18. Hick, P., B.V. Jackson, R.C. Altrock, G. Woan and G. Slater, "IPS Observations of Heliospheric Density Structures Associated with Active Regions", *Adv. in Space Res.* **17**, No. 4/5 (1996) (pg. 311-314). +

19. Altrock, R.C., P. Hick, B.V. Jackson, J.T. Hoeksema, X.P. Zhao, G. Slater, T.W. Henry, "Solar Coronal Structure: A comparison of NSO/SP Ground-Based Coronal Emission Line Intensities and Temperatures with Yohkoh SXT and WSO Magnetic Field Data", *Adv. in Space Res.* **17**, No. 4/5 (1996) (pg. 235-238). +

20. Webb, D.F., B.V. Jackson and P. Hick, "Effects of CMEs on the Heliosphere and GM Storms using Helios Data", in the proceedings of the Fifth Solar-Terrestrial Physics Workshop, Japan, January (1996) (accepted) (4 pages). +

21. Buffington, A., B.V. Jackson, and C.M. Korendyke, "Wide-angle stray-light reduction for a spaceborne optical hemispherical imager", *Applied Optics*, **35** (1996) (pg. 6669-6673).

22. Jackson, B.V., Buffington, A., Hick, P., Kahler, S.W., Keil, S.L.,Altrock, R.C., Simnett, G.M. and Webb, D.F., "The Solar Mass Ejection Imager", in the proceedings of the 42nd International Instrument Symposium, held May 5-9 in San Diego, California (1996) (pg. 17-24).

23. Keil, S.L, R.C. Altrock, S.W. Kahler, B.V. Jackson, A. Buffington, P.L. Hick, G. Simnett, C. Eyles, D.F. Webb, and P. Anderson, "The Solar Mass Ejection Imager (SMEI)", Denver 96 "Missions to The Sun" SPIE Conference **Vol. 2804** (1996) (pg. 78-89).

24. Jackson, B.V., "The active corona observed from space; coronal mass ejections", in The Reports on Astronomy from Commissions 10, 12 and 49 (of the International Astronomical Union, O. Engvold, ed. (1996) (pg. 28-29).

25. Kojima, M., K. Asai, B.V. Jackson, P.L. Hick, M. Tokumaru, H. Watanabe, A. Yokobe, and,"Solar wind structure at 0.1-1 AU reconstructed from IPS observations using tomography", in *Robotic exploration close to the Sun: Scientific Basis*, S.R. Habbal, ed., AIP Conference proceedings 385, New York (1997) (pg. 97-104). +

26. Jackson, B.V., "Heliospheric Observations of Solar Disturbances and Their Potential Role in the Origin of Geomagnetic Storms", in *Magnetic Storms*, Geophysical Monograph Series **98**, B.T. Tsurutani, W.D. Gonzales, Y. Kamide and J.K. Arballo, eds. (1997) (pg. 59-76). +

27. Jackson, B.V., P.L. Hick, M. Kojima and A. Yokobe, "Heliospheric Tomography Using Interplanetary Scintillation Observations", in *Adv. Space Res.* for the COSPAR XXXI meeting held in Birmingham, England 14-21 July (1996) *Adv. in Space Res.*, **20**, No. 1 (1997) (pg. 23-26). +

28. Jackson, B.V., P.L. Hick, M. Kojima and A. Yokobe, "Heliospheric tomography using interplanetary scintillation observations", in the *Physics and Chemistry of the Earth* (1997) (accepted) (10 pages). +

29. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler, G. Simnett and D.F. Webb, "The solar mass ejection imager", in the *Physics and Chemistry of the Earth* (1997) (accepted) (4 pages). +

30. Kojima, M., K. Asai, M. Tokumaru, H. Watanabe, A. Yokobe, B.V. Jackson and P.L. Hick, "Solar Wind Structure at 0.1-1 AU Reconstructed from IPS Observations Using Tomography", to the third SOLTIP workshop on solar transient phenomena held in Bejing, China, 14-18 October (1996) (accepted) (6 pages). +

31. Jackson, B.V., P.L. Hick, M. Kojima and A. Yokobe, "Heliospheric Tomography Using Interplanetary Scintillation Observations I - Combined Nagoya and Cambridge data", *J. Geophys. Res.* (1997) (accepted) (15 pages). +

32. Kojima, M., M. Tokumaru, H. Watanabe, A. Yokobe, K. Asai, Jackson, B.V., and P.L. Hick, "Heliospheric Tomography Using Interplanetary Scintillation Observations II - Latitude and Heliocentric Distance Dependence of Solar Wind Structure at 0.1-1 AU", *J. Geophys. Res.* (1997) (accepted) (14 pages). +

33. Asai, K., M. Kojima, M. Tokumaru, A. Yokobe, B.V. Jackson, P.L. Hick, and P.K. Manoharan, "Heliospheric Tomography Using Interplanetary Scintillation Observations III - The Velocity Dependence of Electron Density Fluctuations in the Solar Wind", *J. Geophys. Res.* (1997) (accepted) (12 pages). +

Work In Progress:

34. Jackson, B.V. and D.F. Webb, "The Speeds of CMEs in the Heliosphere", *J. Geophys. Res.* (1996) (submitted) (8 pages). +

35. Leinert, Ch. and B.V. Jackson, "Global Heliospheric Solar Wind Changes Over Solar Cycle 21: A Comparison of Helios Photometer, In-situ and IPS data", *Astrphys. J.* (1996) (submitted) (10 pages). +

+ Acknowledges UCSD AFOSR contract

Abstracts

There were 60 abstracts for talks which benefitted from our three-year AFOSR–94–0070 research contract. These are:

1. Jackson, B.V., "The Three-dimensional Reconstruction of Two Coronal Mass Ejections", AGU fall meeting, 1993, *EOS*, **74**, 484 (1993).
2. Hick, P. and B.V. Jackson, "Synoptic Comparison of IPS and YOHKOH Soft X-ray Observations", AGU fall meeting, 1993, *EOS*, **74**, 496 (1993).
3. Webb, D.F., B.V. Jackson, P Hick, "Geomagnetic Storms and Heliospheric CMEs as Viewed From HELIOS", AGU fall meeting, 1993, *EOS*, **74**, 486 (1993).
4. Altrock, R.C., P. Hick, G. Slater, B.V. Jackson, T.W. Henry, "Solar Coronal Structure: A Comparison of NSO/SP Ground-Based Coronal Emission Line Intensities and Temperatures with Yohkoh SXT and WCO Magnetic Field Line Data", AGU fall meeting, 1993, *EOS*, **74**, 495 (1993).
5. Rappoport, S.A., P.L. Hick, B.V. Jackson, J.T. Gosling, J.L. Phillips, G. Woan, "The Comparison of Interplanetary Scintillation Synoptic G-Maps with IMP and Ulysses In-situ Plasma Observations", AGU spring meeting, 1994, *EOS*, **75**, 258 (1994).
6. Altrock, R.C., P. Hick, B.V. Jackson, J.T. Hoeksema, X.P. Zhao, G. Slater and T.W. Henry, "The Large-Scale Structure of Coronal Temperature and Global Potential Magnetic Field", AGU spring meeting, 1994, *EOS*, **75**, 281 (1994).
7. Jackson, B.V., "Heliospheric Imaging - a Global View of Solar Wind Structures", AGU spring meeting, 1994, *EOS*, **75**, 279 (1994).

8. Jackson, B.V., "The Analysis and Display of Three-Dimensional Heliospheric Structures", presented at the second SOLTIP symposium held 13 - 17 June, 1994 in Nakaminato, Japan (1994).

9. Altrock, R.C., P. Hick, B.V. Jackson, J.T. Hoeksema, X.P. Zhao, G. Slater, T.W. Henry, "Solar Coronal Structure: A comparison of NSO/SP Ground-Based Coronal Emission Line Intensities and Temperatures with Yohkoh SXT and WSO Magnetic Field Data", to COSPAR, Hamburg, Germany, July (1994).

10. Hick, P.L., B.V. Jackson, R.C. Altrock, G. Woan and G. Slater, "IPS Observations of Heliospheric Density Structures Associated with Active Regions", to COSPAR, Hamburg, Germany, July (1994).

11. Jackson, B.V. and L.A. Lones, "Coronagraph Stray Light Analyses" to the 15th NSO/Sac. Peak Workshop: IR Tools for Solar Astrophysics: What's Next? Sunspot, New Mexico, 19-23 September (1994).

12. Altrock, R.C., P. Hick, B.V. Jackson, J.T. Hoeksema, X.P. Zhao, G. Slater and T.W. Henry, "Association of Solar Coronal Temperature Structure from Ground-Based Emission-Line Data with Global Magnetic Field Models and Yohkoh SXT Data", to the 15th NSO/Sac. Peak Workshop: IR Tools for Solar Astrophysics: What's Next? Sunspot, New Mexico, 19-23 September (1994).

13. Jackson, B.V., D.F. Webb, "CME Masses Measured in the Inner Heliosphere from the Helios Spacecraft Photometers", to the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, 25-29 September (1994).

14. Webb, D.F. and B.V. Jackson, "Comparison of CME Masses Measured Near the Sun and in the Inner Heliosphere", to the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, 25-29 September (1994).

15. Jackson, B.V., P.L. Hick, "Three Dimensional Reconstruction of Coronal Mass Ejections", to the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, 25-29 September (1994).

16. Hick, P., B.V. Jackson, R.C. Altrock, K.T. Strong, G. Slater, T. Henry, "Observations of the annular solar eclipse of 10 May 1994", AGU fall meeting, 1994, *EOS*, **75**, 518 (1994).

17. Jackson, B.V., P.L. Hick, R.C. Altrock, G. Woan and M. Kojima, "Velocity and Scintillation-Level IPS Carrington Synoptic Comparisons with Ulysses Polar Data", AGU fall meeting, 1994, *EOS*, **75**, 518-519 (1994).

18. Webb, D.F. and B.V. Jackson, "CME Masses Measured in the Inner Heliosphere Using HELIOS Photometer Data", AGU fall meeting, 1994, *EOS*, **75**, 528 (1994).

19. Jackson, B.V. and D.F. Webb, "The Mass and Energy Distributions of CMEs Measured by Solwind and HELIOS", AGU spring meeting special session 'Is the Solar Flare Myth Really a Myth?', 1995, *EOS*, **76**, S224 (1995).

20. Jackson, B.V. and D.F. Webb, "CME Masses Measured by the HELIOS Spacecraft Photometers", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

21. Webb, D.F., R.A. Howard and B.V. Jackson, "Comparison of CME Masses and Kinetic Energies Near the Sun and in the Inner Heliosphere", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

22. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler, R.C. Altrock, R.E. Gold and D.F. Webb, "The Solar Mass Ejection Imager", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

23. P. Hick and B.V. Jackson, "Evidence of Active Region Imprints on the Solar Wind Structure", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

24. P. Hick, B.V. Jackson and R. Altrock, "Coronal Synoptic Temperature Maps Derived from the Fe XIV/Fe X Intensity Ratio", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

25. G.L. Slater, J.R. Lemen, P. Hick and B.V. Jackson, "Yohkoh/SXT X-ray Synoptic Maps of Coronal Brightness and Temperature", presented at Solar Wind 8 held in Dana Point, California 26-30 June (1995).

26. B.V. Jackson, P. Hick and R. Altrock, "Coronal Synoptic Temperature Maps Derived from the Fe XIV/Fe X Intensity Ratio", presented at the Japan Astronomical Society Meeting held in Niigata, Japan 5-7 October (1995).

27. Jackson, B.V., A. Buffington, P. Hick, S.W. Kahler, S.L. Keil, R.C. Altrock, G.M. Simnett and D.F. Webb, "The Solar Mass Ejection Imager", International Workshop: Small Mission Opportunities and the Scientific Community, Colleferro, Italy, 12-13 October (1995).

28. B.V. Jackson, "White-light Heliospheric Observations of Solar Mass Ejections", to the Nagoya Mini-Conference, Nagoya, Japan held 13 October (1995).

29. Hick, P. and B.V. Jackson, "The Influence of Active Regions on IPS Measurements near 1 AU", 16th NSO/Sacramento Peak International Workshop: Solar Drivers of Interplanetary and Terrestrial Disturbances, Sunspot, NM, 16-20 October (1995).

30. Hick, P., B.V. Jackson, R.C. Altrock, G. Slater and T. Henry, "The Coronal Temperature Structure and the Current Sheet", 16th NSO/Sacramento Peak International Workshop: Solar Drivers of Interplanetary and Terrestrial Disturbances, Sunspot, NM, 16-20 October (1995).

31. Webb, D.F., B.V. Jackson and P. Hick, "Geomagnetic Storms and Heliospheric CMEs Using HELIOS Photometer Data", 16th NSO/Sacramento Peak International Workshop: Solar Drivers of Interplanetary and Terrestrial Disturbances, Sunspot, NM, 16-20 October (1995).

32. B.V. Jackson, M. Kojima, and P.L. Hick, "Forecasts of Co-Rotating Solar Wind Features Using IPS", to the Nagoya Predictions Conference, Nagoya, Japan 25-27 October (1995).

33. Webb, D.F., B.V. Jackson and P. Hick, "Effects of CMEs on the Heliosphere and GM Storms using Helios Data", Fifth Solar-Terrestrial Physics Workshop, Japan, January (1996).

34. Jackson, B.V., "Heliospheric Observations of Solar Disturbances and Their Potential Role in the Origin of Solar Storms", in the proceedings of the Chapman Conference on Magnetic Storms held February 12-16 1996 at JPL, Pasadena, California (1996).

35. Kojima, M., K. Asai, M. Tokumaru, H. Watanabe, A. Yokobe, B.V. Jackson and P.L. Hick, "Solar wind structure at 0.1-1 AU reconstructed from IPS observations using tomography method", to the workshop on Scientific Basis for Robotic Exploration close to the Sun, Marlboro, MA, 15-18 April (1996).

36. Jackson, B.V., P.L. Hick and M. Kojima, "Heliospheric tomography using interplanetary scintillation observations", EGS XXI meeting, the Hague, the Netherlands, 6-10 May (1996).

37. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler, G. Simnett and D.F. Webb, "The solar mass ejection imager", EGS XXI meeting, the Hague, the Netherlands, 6-10 May (1996).

38. Odstrcil, D., B. Jackson and T. Watanabe, "Numerical magnetohydrodynamic simulation of interplanetary disturbances associated with a coronal mass ejection on 27 November 1979", EGS XXI meeting, the Hague, the Netherlands, 6-10 May (1996).

39. Jackson, B.V., A. Buffington, P. Hick, S.W. Kahler, S.L. Keil, G. Simnett and D.F. Webb, "The Solar Mass Ejection Imager", Instrument Society of America Conference, San Diego, CA, 6-10 May (1996).

40. Jackson, B.V. and P.L. Hick, "Heliospheric Tomography Using Helios Spacecraft Photometer (Thomson Scattering) and Interplanetary Scintillation Velocity Observations", AGU spring meeting, 1996, *EOS*, **77**, S216 (1996).

41. Korendyke, C.M., G.E. Brueckner, J.W. Cook, R.A. Howard, D.K. Prinz, D.G. Socker, N.E. Moulton, A. Buffington, P. Hick and B.V. Jackson, "All-Sky and High Resolution Coronagraphs for FIRE", Denver 96 "Missions to The Sun" SPIE Conference (1996).

42. Jackson, B.V., P.L. Hick and M. Kojima, "Heliospheric tomography using interplanetary scintillation observations", COSPAR XXXI meeting, Birmingham, England 14-21 July (1996).

43. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler, G. Simnett and D.F. Webb, "The solar mass ejection imager", COSPAR XXXI meeting, Birmingham, England 14-21 July (1996).

44. Webb, D.F., and B.V. Jackson, "The mass and energy of CMEs and X-ray flares", COSPAR XXXI meeting, Birmingham, England 14-21 July (1996).

45. Altrock, R.C., P. Hick, B.V. Jackson, G. Slater and T.W. Henry, "The Solar Coronal Temperature Structure and the Heliospheric Current Sheet", *BAAS*, **28**, 956-957 (1996).

46. Kojima, M., K. Asai, M. Tokumaru, H. Watanabe, A. Yokobe, B.V. Jackson and P.L. Hick, "Solar wind structure at 0.1-1 AU reconstructed from IPS observations using tomography", to the third SOLTIP workshop on solar transient phenomena held in Bejing, China, 14-18 October (1996).

47. Buffington, A., B.V. Jackson and P. Hick, "Precision Photometric Heliospheric Measurements with the Solar Mass Ejection Imager", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F557 (1996).

48. Jackson, B.V. and P. Hick, "Coronal Velocity Determination Using Two-Dimensional Correlation Techniques", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F562 (1996).

49. Hick, P., B.V. Jackson, R.C. Altrock and T. Henry, "Large-scale coronal temperature structure during solar cycle 22 as derived from the Fe X and Fe XIV intensity", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F566 (1996).

50. Keil, S.L., R. C. Altrock, S. W. Kahler, B.V. Jackson, A. Buffington, P.L. Hick, G. Simnett, C. Eyles, D.F. Webb and P. Anderson, "The Solar Mass Ejection Imager (SMEI)", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F568 (1996).

51. Leinert, Ch. and B.V. Jackson, "Global Heliospheric Solar Wind Changes Over Solar Cycle 21: A Comparison of Helios Photometer, In-situ and IPS Data", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F568 (1996).

52. Webb, D.F. and B.V. Jackson, "Heliospheric Imaging Using the Helios Photometers and Thomson Scattering Techniques", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F568 (1996).

53. Woan, G. and B.V. Jackson, "Scintillation Imaging of Space Plasmas", AGU fall meeting, 1996, *EOS*, **77**, No. 46 Supplement, F568 (1996).

54. Jackson, B.V. and P.L. Hick, "Tomography of Heliospheric Structures Using Helios Spacecraft Photometer Data", SPD/AAS June-July Meeting, 1997, *BAAS*, **29**, 919 (1997).

55. Keil, S.L., R.C. Altrock, S.W. Kahler, B.V. Jackson, A. Buffington, P.L. Hick, G. Simnett, C. Eyles, D.F. Webb, P. Anderson, "Design for the Solar Mass Ejection Imager (SMEI)", SPD/AAS June-July Meeting, 1997, *BAAS*, **29**, 897 (1997).

56. Jackson, B., P. Hick and M. Kojima, "The Three Dimensional Tomography of Heliospheric Features", to the IAU #23 in Kyoto, Japan, August, 1997, *IAU Abstract Book*, 102 (1997).

57. Jackson, B. and P. Hick, "Coronal Velocity Determination Using Two-Dimensional Correlation Techniques", to the IAU #23 in Kyoto, Japan, August, 1997, *IAU Abstract Book*, 106 (1997).

58. Jackson, B., A. Buffington, P. Hick, S. Keil, R. Altrock, S. Kahler, G. Simnett, C. Eyles, D. Webb, P. Anderson, "The Solar Mass Ejection Imager (SMEI)", to the IAU #23 in Kyoto, Japan, August, 1997, *IAU Abstract Book*, 107 (1997).

59. Yokobe, A., K. Asai, P. L. Hick, B.V. Jackson, M. Kojima, P.K. Manoharan, M. Tokumaru and H. Watanabe, "Solar Wind Structure Analyzed by Tomography of Interplanetary Scintillation", to the IAU #23 in Kyoto, Japan, August, 1997, *IAU Abstract Book*, 113 (1997).

60. Jackson, B. and P. Hick, "Two Dimensional Velocity Correlations of CME Features", to the AGU fall meeting (1997).

III.F. UCSD Personnel Supported by this Contract

1. B. Jackson – Research Physicist
2. P. Hick – Assistant Project Scientist
3. T. Davidson – student
4. R. Yumul – student
5. D. Boyd – student
6. P. Hsu – student
7. J. Nelson – student
8. L. Lones – student
9. S. Rappoport – student
10. T. Lee – student
11. R. Vuong – student
12. S. Pettijohn – secretary

IV. Conclusions

Much work has been accomplished from the comparison of HELIOS photometer observations with coronagraph observations and other data. We have begun new studies by using the whole data set more effectively. Our data base provides a uniform and sensitive observational foundation for long-term global studies. The wealth of data provides a statistical base to study the effect of each event and its comparison to other known manifestations of the event. One further objective of the study with D. Webb at the Geophysics Lab is to continue and extend our work on mass ejections and co-rotating structures.

The outcome of the Cambridge, England intensity IPS data comparison with other data sets leaves much to be desired as far as its use as a disturbance forecast technique is concerned. However, we pursued these comparisons as solar activity declined in the hope that co-rotating features of the solar wind become more dominant, and allow a more fruitful forecast of corotating structures at times of low solar activity. From the comparison of YOHKOH X-ray images and IPS data, we discovered that active regions play a dominant role in the solar wind. With this understanding we are far better able to forecast conditions at Earth from processes in the quiet solar wind. We also discovered that the regions of high temperature generally follow the heliospheric current sheet, and have written or helped write papers on many aspects of these observations.

Our tomographic heliospheric reconstructions became formalized into a more robust system which allows the mapping of many different types of data sets. These data sets

include observations from the HELIOS photometers as well as both scintillation level and velocity data from a variety of different ground-based instruments. The basic difference between these and previous reconstructions is that they allow measurements to be obtained from nearly any coordinate system and they use both solar wind outward motion as well as solar rotation to provide perspective views. In theory, this permits three dimensional reconstruction of global heliospheric data sets even though they are obtained from a single location in space.

These studies are of vital interest to the Air Force. This interest goes beyond a wish to know the detail of how the processes work in order to form a more comprehensive understanding of them. In each case for this research we include in the study the possibility of being able to forecast the arrival of these structures at Earth or their occurrence prior to their manifestations in the near-Earth environment.

In summary, the object of this research has been to study the problems associated with heliospheric plasma processes by viewing interplanetary structures. Prior to our development of new methods to determine heliospheric structures, studies of these features had to rely on large, incomplete extrapolations from *in situ* spacecraft measurements and near-solar surface observations. This research will greatly enhance the study of these heliospheric structures to the point that it will be possible to tell how they interact quantitatively with the Earth. The quantitative assessments include the basic heliospheric structure parameters which affect Earth such as shape, mass, speed and magnetic field. These parameters are not currently available by any other means.

References

1. Altrock, R.C., Hick, P., Jackson, B.V., Hoeksema, J.T., Zhao, X.P., Slater, G. and Henry, T.W., 1994, *Adv. in Space Res.* **17**, No. 4/5, 235.
2. Asai, K., Kojima, M. Tokumaru, M., Yokobe, A., Jackson, B.V., Hick, P.L., and Manoharan, P.K., 1997, *J. Geophys. Res.* (accepted).
3. Behannon, K.W, Burlaga, L.F. and Hewish, A., 1991, *J. Geophys. Res.*, **96**, 21,213.
4. Cliver, E.W., Dennis, B.R., Kiplinger, A.L., Kane, S.R., Neidig, D.F., Sheeley, N.R., Jr. and Koomen, M.J., 1986, *Astrophys. J.*, **305**, 920.
5. Coles, W.A. and Kaufman, J.J., 1978, *Radio Science*, **13**, 591.
6. Crooker, N.U., Siscoe, G.L., Shodhan, S., Webb, D.F., Gosling, J.T. and Smith, E.J., 1993, *J. Geophys. Res.*, **98**, 9371.
7. Farnik, F., van Beek, H.F. and Švestka, Z., 1986, *Solar Phys.*, **104**, 321.
8. Fisher, R. and Sime, D.G., 1984, *Astrophys. J.*, **285**, 354.
9. Frost, K.J. and Dennis, B.R., 1971, *Astrophys. J.*, **165**, 655.
10. Guhathakurta, M., Fisher, R.R. and Altrock, R.C., 1993, *Astrophys. J. Letts.*, 145.
11. Harrison, R.A., Waggett, P.W., Bentley, R.D., Phillips, K.J.H., Bruner, M., Dryer, M. and Simnett, G.M., 1985, *Solar Phys.*, **97**, 387.
12. Hewish, A and Bravo, S., 1986, *Solar Phys.*, **106**, 185.

13. Hick, P. and Jackson, B., 1994, *Adv. in Space Res.* **14**, 135.

14. Hick, P. and Jackson, B.V., 1995, in *Solar Wind Eight*, D. Winterhalter, J.T. Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury, 461.

15. Hick, P., Švestka, Z., Smith, K.L. and Strong, K.T., 1987, *Solar Phys.*, **114**, 329.

16. Hick, P., Jackson, B.V. and Schwenn, R., 1990, *Astron. Astrophys.* **285**, 1.

17. Hick, P.L., Jackson, B.V. and Schwenn, R., 1992, in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, 187.

18. Hick, P.L., Jackson, B.V. and Webb, D.F., 1993, *BAAS*, **25**, 1210.

19. Hick, P., Jackson, B.V., Rappoport, S., Woan, G., Slater, G., Strong, K., and Uchita, Y., 1995, *Geophys. Res. Lett.*, **22**, 643.

20. Hick, P., Jackson B.V., and Altrock, R., 1995, in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury, 169.

21. Hick, P., Jackson, B.V., Altrock, R.C., Woan, G. and Slater, G., 1996, *Adv. in Space Res.* **17**, No. 4/5, 311.

22. Hoeksema, J.T., Wilcox, J.M. and Scherrer, P.H., 1983, *J. Geophys. Res.*, **88**, 9910.

23. Hudson, H.S., 1978, *Astrophys. J.*, **224**, 235.

24. Jackson, B.V., 1985, *Solar Phys.*, **100**, 563.

25. Jackson, B.V., 1989, *Adv. Space Res.*, **9**, 69.

26. Jackson, B.V., 1991a, *J. Geophys. Res.*, **96**, 11,307.

27. Jackson, B.V., 1991b, presented at Solar Wind 7 held in Goslar, Germany 16-21 September 1991.

28. Jackson, B.V., 1991c, in Proceedings of the First SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October, S. Fischer and M. Vandas, eds. Astronomical Institute of the Czechoslovak Academy of Sciences, Prague, 153.

29. Jackson, B.V., 1996, in The Reports on Astronomy from Commissions 10, 12 and 49 (of the International Astronomical Union, O. Engvold, ed., 28.

30. Jackson, B.V., 1997, in *Magnetic Storms*, Geophysical Monograph Series **98**, B.T. Tsurutani, W.D. Gonzales, Y. Kamide and J.K. Arballo, eds., 59.

31. Jackson, B.V. and Howard, R.A., 1993, *Solar Phys.* **148**, 349.

32. Jackson, B.V. and Hick, P.L., 1994, in the proceedings of the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, esa **SP-373**, 199.

33. Jackson, B.V. and Webb, D.F., 1994, in the proceedings of the Third SOHO Workshop on Solar Dynamic Phenomena & Solar Wind Consequences, esa **SP-373**, 233.

34. Jackson, B.V. and Froehling, H.R., 1995, *Astron. Astrophys.*, **299**, 885.

35. Jackson, B.V. and Hick, P.L., 1996, AGU spring meeting, *EOS*, **77**, S216.

36. Jackson, B.V. and Webb, D.F., 1997, *J. Geophys. Res.* (submitted).

37. Jackson, B.V. and Hick, P.L., 1997, SPD/AAS June-July Meeting, 1997, *BAAS*, **29**, 919.

38. Jackson, B.V., Rompolt, B. and Švestka, Z., 1988, *Solar Phys.*, **115**, 327.

39. Jackson, B.V., Hick, P.L. and Webb, D.F., 1993, *Adv. in Space Res.*, **13**, 43.

40. Jackson, B.V., Webb, D.F., Hick, P.L. and Nelson, J.L., 1994, *PL-TR-94-2040, Scientific Report No. 4*, Phillips Laboratory, Hanscom.

41. Jackson, B.V., Buffington, A., Hick, P.L., Kahler, S.W., Altrock, R.C., Gold, R.E. and Webb, D.F., 1995, in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury, 536.

42. Jackson, B.V., Hick, P.L., Kojima, M. and Yokobe, A., 1997a, in *Adv. Space Res.* for the COSPAR XXXI meeting held in Birmingham, England 14-21 July (1996) *Adv. in Space Res.*, **20**, No. 1, 23.

43. Jackson, B.V., Hick, P.L., Kojima, M. and Yokobe, A., 1997b, *J. Geophys. Res.*, (accepted).

44. Kahler, S.W., 1977, *Astrophys. J.*, **214**, 891.

45. Kahler, S.W., Hildner, E. and van Hollebeke, M.A.I., 1978, *Solar Phys.*, **57**, 429.

46. Keil, S.L, Altrock, R.C., Kahler, S.W., Jackson, B.V., Buffington, A., Hick, P.L., Simnett, G., Eyles, C., Webb, D.F. and Anderson, P., 1996, Denver 96 "Missions to The Sun" SPIE Conference **Vol. 2804**, 78.

47. Kojima, M., Asai, K., Jackson, B.V., Hick, P.L., Tokumaru, M., Watanabe, H., Yokobe, A. and Manoharan, P.K., 1997a, in *Robotic exploration close to the Sun: Scientific Basis*, S.R. Habbal, ed., AIP Conference proceedings 385, New York, 97.

48. Kojima, M., Tokumaru, M., Watanabe, H., Yokobe, A., Asai, K., Jackson, B.V., and Hick, P.L., 1997b, *J. Geophys. Res.* (accepted).

49. Leinert, Ch. and Jackson, B.V., 1997, *Astrphys. J.* (submitted).

50. Leinert, C., Link, H. and Salm, N., 1981, *J. Space Sci. Instr.*, **5**, 257.

51. MacQueen, R.M., 1993, *Solar Phys.*, **145**, 169.

52. Richter, I., Leinert, C. and Planck, B., 1982, *Astron. Astrophys.*, **110**, 115.

53. Rickett B.J., and Coles, W.A., 1991, *J. Geophys. Res.*, **96**, 1717.

54. Rust, D.M., Hildner, E. and 11 co-authors, 1980, Introduction in *Solar Flares, A Monograph from Skylab Solar Workshop II* (ed. P.A. Sturrock), Colorado Associated Press.

55. Sheeley, N.R., Jr., Howard, R.A. and Michels, D.J., 1983, *Astrophys. J.*, **272**, 349.

56. Sheeley, N.R., Jr., Howard, R.A., Koomen, M.J., Michels, D.J., Schwenn, R., Mühlhäuser, K.H., 1985, *J. Geophys. Res.*, **90**, 163.

57. Shodhan-Shah, S., Crooker, N.U., Hughes, W.J., Webb, D.F., Jackson, B.V. and Siscoe, G.L., 1993, *EOS*, **74**, 238.

58. Švestka, Z., 1981, in E.R. Priest (ed), *Flare Magnetohydrodynamics* (Gordon and Breach), p. 47.

59. Švestka, Z., 1984, *Solar Phys.*, **94**, 171.

60. Švestka, Z, 1986, in D.F. Neidig (ed.), *Proceedings of the NSO/SMM Symposium: The Lower Atmosphere of Solar Flares*, p. 332.

61. Švestka, Z. and 14 co-authors, 1982a, *Solar Phys.*, **75**, 305.

62. Švestka, Z., Dennis, B.R., Pick, M., Raoult, A., Rapley, C.G., Stewart, R.T. and Woodgate, B.E., 1982b, *Solar Phys.*, **80**, 143.

63. Tsuneta, S. and 9 co-authors, 1984, *Astrophys. J.*, **280**, 887.

64. Webb, D.E. and Kundu, M., 1978, *Solar Phys.*, **57**, 155.

65. Webb, D.F. and Jackson, B.V., 1988, *Proc. of the 6th Intl. Solar Wind Conference*, NCAR TN-306 Technical Proc., Boulder, 267.

66. Webb, D.F. and Jackson, B., 1990, *J. Geophys. Res.*, **95**, 20641.

67. Webb, D.F. and Crooker, N.U., 1991, presented at Solar Wind Seven held in Goslar, Germany 16-21 September 1991.

68. Webb, D.F. and Jackson, B.V., 1992, in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, 681.

69. Webb, D.F. and Jackson, B.V., 1993, in the *Solar Terrestrial Predictions Workshop 4* in Ottawa, Canada 18 - 22 May, A. Huruska *et al.* eds., NOAA, Boulder, 381.

70. Webb, D.E., Cheng, C.C., Dulk, G.A., Edberg, S.J., Martin, S.F., McKenna-Lawlor, S. and McLean, D.J., 1980, in *Solar Flares, A Monograph from Skylab Solar Workshop II* P.A. Sturrock, ed., Colorado Associated Press, 471.

71. Webb, D.F., Jackson, B.V., Hick, P., Schwenn, R., Bothmer, V. and Reames, D., 1993a, *Adv. in Space Res.*, **13**, 71.

72. Webb, D.F., Jackson, B.V., Hick, P., 1993b, *EOS*, **74**, 486.

73. Webb, D.F., Howard R.A. and Jackson, B.V., 1995, in *Solar Wind Eight*, D. Winterhalter, J.T.Gosling, S.R. Habbal, W.S. Kurth and M. Neugebauer, eds., AIP Conference Proceedings 382, Woodbury, 540.

74. Winfield, K.A., Rappoport, S.A., Nelson, J.A., Lang, J.P., Lones, L.A., Jones, J.A., Jackson, B.V., Hick, P.L. and Davidson, T.E., 1993, *BAAS*, **24**, 1254.